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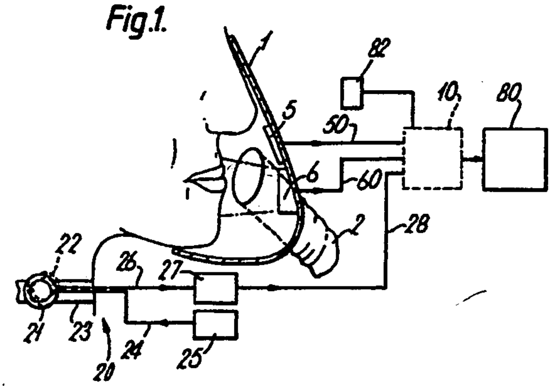
(54) Speech recognition apparatus and methods.

(57) Speech recognition apparatus has a television camera or optical array 6 that views the mouth of a speaker, and a larynogograph 20 that detects movement of the vocal folds. A microphone 5 produces an output in respect of the sound produced by the speaker. After visual processing, signals from the camera 6 are supplied to a pattern matching unit 63 together with signals from a store 64. Signals from the laryngograph are also supplied to the pattern matching unit to resolve ambiguity between speech sounds withsimilar mouth shapes. the output of the microphone is supplied to a noise adaptation unit 52 together with laryngograph output which enables external noise to be identified and rejected. After noise adaptation, the microphone output is subjected to pattern matching with a vocabulary 54 of reference templates. Signals representing the most likely fit after the two pattern matching processes are supplied to a comparator 70 which selects the most likely word spoken, or signals the speaker, via a feedback device 82, to repeat the word spoken.

Fig.1.



lip sync.

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SPEECH RECOGNITION APPARATUS AND METHODS

This invention relates to speech recognition apparatus.

In complex equipment having multiple functions it can be useful to be able to control the equipment by spoken commands. This is also useful where the user's hands are occupied with other tasks or where the user is disabled and is unable to use his hands to operate conventional mechanical switches and controls.

The problem with equipment controlled by speech is that speech recognition can be unreliable, especially in noisy environments. This can lead to failure to operate or, worse still, to incorrect operation.

Speech signal processing can also be used in communicaton systems, where the speech input is degraded by noise, to improve the quality of speech output. This generally involves filtering and signal enhancement but usually results in some loss of the speech information where high noise is present.

It is the object of the present invention to provide speech recognition apparatus and methods that can be used to improve speech handling.

According to one aspect of the present invention there is provided speech recognition apparatus, characterised in that the apparatus includes an optical device mounted to view a part at least of the mouth of a speaker, the optical device providing an output that varies with movement of the speaker's mouth, voicing sensing apparatus that detects movement of the speaker's vocal folds such as thereby to derive information regarding the voiced sounds of the speaker, and a processing unit that derives from the output of the optical device and the voicing sensing apparatus information as to the speech sounds made by the speaker.

The voicing sensing apparatus preferably includes a laryngograph responsive to changes in impedance to electromagnetic radiation during movement of the vocal folds. The apparatus may include a store containing information of a reference vocabulary of visual characteristics of the speaker's mouth, and a first pattern matching unit that selects the closest match between the output of the optical device and the vocabulary in the store and provides an output representative of the selected speech sounds. The output from the voicing sensing apparatus may be supplied to the first pattern matching unit to improve identification of the speech sounds.

The apparatus may include a microphone that derives an output in respect of the sound produced by the speaker, and a comparator that compares the output from the microphone with information derived from the optical device such as to derive information concerning speech sounds made by the speaker. The output of the voicing sensing apparatus and the microphone are preferably combined in order to identify sound originating from the speaker and sound originating from external sources.

The apparatus preferably includes a store containing a reference vocabulary of sound signal information, a second pattern matching unit connected to the store and connected to receive the output of the microphone after rejecting signals associated with sounds originating from exteranl sources. The comparator preferably receives the outputs of the first and second pattern matching units and provides an output representing the most probable speech sounds made in accordance therewith.

The apparatus may include a circuit that modifies the output of the microphone. The output of the microphone may modified by the output of the first pattern matching unit, the output of the microphone being supplied to the second pattern matching unit after modification by the first pattern matching unit.

Speech recognition apparatus and its method of operation, in accordance with the present invention, will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a side elevation view of a user wearing a breathing mask;

Figure 2 is a front elevation view of the mouth of the user;

Figure 3 illustrates schematically the apparatus; and

Figure 4 illustrates schematically aternative apparatus.

With reference first to Figures 1 and 2, there is shown a speaker wearing a breathing mask 1 having an air supply line 2 that opens into the mask on the side. An exhaust valve, not shown, is provided on the other side in the conventional way. The mask 1 also supports a microphone 5 that is located to detect speech by the user and to supply electrical output signals on line 50, in accordance with the speech and other sounds within the mask, to a speech recignition unit 10.

Also mounted in the mask 1 is a small, lightweight CCD television camera 6 which is directed to view the region of the user's mouth including an area immediately around the mouth, represented by the pattern in Figure 2. Preferably, the camera 6 is response to infra-red radiation so that it does not require additional illumination. Alternatively, the

camera 6 may be responsive to visible or ultraviolet radiation if suitable illumination is provided. Signals from the camera 6 are supplied via line 60 to the speech recognition unit 10.

The speech recognition apparatus also includes a laryngograph 20 of conventional construction such as described in ASHA Reports 11, 1981, p 116 -127. The larngograph 20 includes two electrodes 21 and 22 secured to the skin of the user's throat by means of a neck band 23. The electrodes 21 and 22 are located on opposite sides of the neck, level with the thyroid cartilage. Each electrode 21 and 22 is flat and circular in shape being between 15 and 30mm in diameter, with a central circular plate and a surrounding annular guard ring insulated from the central plate. One electrode 21 is connected via a coaxial cable 24 to a supply unit 25 which applies a 4MHz transmitting voltage between the central plate and guard ring of the electrode. Typically, about 30mW is dissipated at the surface of the user's neck. The other electrode 22 serves as a current pick-up. Current flow through the user's neck will vary according to movement of the user's vocal folds. More particularly, current flow increases (that is, impendance decreases) when the area of contact between the vocal folds increases, although movement of the vocal folds which does not vary the area of contact will not necessarily produce any change in current flow.

The output from the second electrode 22 is supplied on line 26 to a processing unit 27. The output signal is modulated according to the frequency of excitation of the vocal tract and thereby provides information about phonation or voiced speech, of the user. This signal is unaffected by external noise and by movement of the user's mouth and tongue. The processing unit 27 provides an output signal on line 28 in accordance with the occurrence and frequency of voiced speech, this signal being in a form that can be handled by the speech recognition unit 10.

With reference now also to Figure 3, signals from the microphone 5 are first supplied to a spectral analysis unit 51 which produces output signals in accordance with the freqency bands within which the sounds falls. These signals are supplied to a spectral correction and noise adaptation unit 52 which improves the signal to noise ratio or eliminates, or marks, those speech signals that have been corrupted by noise. The spectral correction unit 52 also receives input signals from the laryngograph 20 on line 28. These signals are used to improve the identification of speech sounds. For example, if the microphone 5 receives signals which may have arisen from voiced speech (that is, speech with sound produced by vibration of the vocal folds) or from external noise, which produces sounds similar to phonemes |z| in 'zero' or |i| in 'hid' but there is no output from the laryngograph 20, then the sound can can only have arisen either from noise or from another class of sound corrupted by noise and is consequently marked as such. Output signals from the unit 52 are supplied to one input of a pattern matching unit 53. The other input to the pattern matching unit 53 is taken from a store 54 containing information form a reference vocabulary of sound signal information in the form of pattern templates or word models of the freqnecy/time patterns or state descriptions of different words. The pattern matching unit 53 compares the frequency/time patterns derived from the microphone 5 with the stored vocabulary and produces an output on line 55 in accordance with the word which is the most likely fit for the sound received by the microphone. The output may include information as to the probability that the word selected from the vocabulary is the actual word spoken. The output may also include signals representing a plurality of the most likely words actually spoken together with their associated probabilities.

The part of the unit 10 which processes the optical information from the camera 6 includes a visual processing unit 61 which receives the camera outputs. The visual processing unit 61 analyses the input signals to identify key characteristics of the optical speech patterns or optical model states from the visual field of the camera, such as, for example, lip and teeth separation and lip shape. In this respect, well-known optical recognition techniques can be used.

The visual processing unit 61 supplies output signals on line 62 to one input of a pattern matching unit 63. A second input to the pattern matching unit 63 is taken from a store 64 containing information of a reference vocabulary in the form of templates of the key visual characteristics of the mouth. Signals from the laryngograph 20 on line 28 are supplied to a third input of the patten matching unit 63 to improve identification of the word spoken. The output of the laryngograph 20 is used to resolve situations where there is ambiguity of the sound produced from observation of mouth movement alone. For example, the sounds |s| and |z| will produce the same output from the visual processing unit 61, but only the sound |z| will produce an output from the larynogograph 20. This thereby enables the pattern matching unit 63 to select the correct sound of the two alternatives. Similarly, some sounds which have the same mouth shape can be identified in the pattern matching unit 63 because they are produced with voicing (phonation) of different freqencies. The pattern matching unit 63 provides an output on line 65 in accordance with the word that best fits the observed mouth movement. The output may also include information as to the probability that the

word selected from the vocabulary is the actual word spoken. The output may also include signals representing a plurality of the most likely words actually spoken with their associated probabilities.

The outputs from the two pattern matching circuits 53 and 63 are supplied to a comparison unit 70 which may function in various way. If both inputs to the comparison unit 70 indicate the same word then the comparison unit produces output signals representing that word on line 71 to a control unit 80 or other untilisation means. If the inputs to the comparison unit 70 indicate different words, the unit responds by selecting the word with the highest associated probability. Where the pattern matching units 53 and 63 produce outputs in respect of a plurality of the most likely words spoken, the comparison unit acts to select the word with the highest total probability. The comparison unit 70 may be arranged to give signals from one or other of the pattern matching units 53 or 63 a higher weighting than the other when selecting between conflicting inputs.

If the comparison unit 70 fails to identify a word with sufficiently high probability it supplies a feedback output on line 72 to a feedback device 82 giving information to the user which, for example, prompts him to repeat the word, or asks him to verify that a selected word was the word spoken. The feedback device 82 may generate an audible or visual signal. A third output on line 73 may be provided to an optional syntax selection unit (not shown) which is used in a known way to reduce the size of the reference vocabulary for subsequent words.

The output signals on line 71 are supplied to the control unit 80 which effects control of the selected function in accordance with the words spoken.

In operation, the user first establishes the reference vocabulary in stores 54 and 64 by speaking a list of words. The apparatus then stores information derived from the sound, voicing and mouth movements produced by the spoken list of words for use in future comparison.

A modification of the apparatus of Figure 3 is shown in Figure 4. In this modification it will be seen that a spectrum substitution unit 74 is interposed between the spectral correction and noise adaptation unit 52 and the pattern matching unit 53. This modification operates to substitute only short-term corrupted speech spectra with a 'most-likely' description of uncorrupted short-term spectra. When the noise detection process caried out by unit 52 indicates that the acoustic spectrum output from the analysis unit 51 has been corrupted by noise, a clean spectrum most likely to be associated with the visual pattern detected by the pattern matching unit 63 is supplied to the input of the unit 53 via a spectrum substitution unit 74 in place of the noisy spectrum otherwise supplied by the unit 52. The spectrum substitution unit 74 transforms the optical pattern recognised by the pattern matching unit 63 into an acoustic pattern with the same structure as the patterns produced at the outputs of the units 51 and 52.

In the present invention, although noise may severly degrade the quality of the sound signal making acoustic recognition of the spoken words impossible, the optical output derived from the camera 6 and the output of the laryngograph 20 will not be affected and this can be used to make a positive recognition. The invention is herefore particularly useful in noisy environments such as factories, vehicles, quarries, underwater, commodity or financial dealing markets and so on.

In some circumstances it may not be necessary to use a microphone since the optical signal and laryngograph outputs may be sufficient to identify the words spoken.

Various alternative optical means could be usd to view the user's mouth. In one example, the end of a fibre-optic cable may be located in the breathing mask and a television camera mounted remotely at the other end of the cable. Alternatively, an array of radiation detectors may be mounted in the breathing mask or remotely via fibre-optic cables to derive signals in accordance with the position and movement of the user's mouth.

Instead of using a laryngograph which detects movement of the vocal folds by change in impedance to transmission of high freqency electromagnetic radiation, various alternative voicing sensing means could be used. For example, it may be possible to sense voicing by ultrasound techniques.

Where the user does not wear a breathing mask, the optical device can be mounted with his head by other means, such as in a helmet, or on the microphone boom of a headset. It is not essential for the optical device to be mounted with the user's head although this does make it easier to view the mouth since the optical field will be independent of head movement. Where the optical device is not mounted on the user's head, additional signal processing will be required to identify the location of the user's mouth. The laryngograph electrodes could be mounted on an extended collar of the user's helmet.

It will be appreciated that the blocks shown in Figure 3 are only schematic and that the functions caried out by the blocks illustrated could be carried out by suitable programming of a single computer.

Claims

1. Speech recognition apparatus, characterised in that the apparatus includes an optical device (6) mounted to view a part at least of the mouth of a speaker, the optical device providing an output that varies with movement of the speaker's mouth, voicing sensing apparatus (20) that detects movement of the speaker's vocal folds such as thereby to derive information regarding the voiced sounds of the speaker, and a processing unit (10) that derives from the output of the optical device (6) and the voicing sensing apparatus (20) information as to the speech sounds made by the speaker.

2. Speech recognition apparatus according to Claim 1, characterised in that the voicing sensing apparatus (20) includes a laryngograph responsive to changes in impedance to electromagnetic radiation during movement of the vocal folds.

3. Speech recognition apparatus according to Claim 1 or 2, characterised in that the apparatus includes a store (64) containing information of a reference vocabulary of visual characteristics of the speaker's mouth, and a first pattern matching unit (63) that selects the closest match between the output of the optical device (6) and the vocabulary in the store (64) and provides an output representative of the selected speech sounds.

4. Speech recognition apparatus according to Claim 3, characterised in that the output from the voicing sensing apparatus (20) is supplied to the first pattern matching unit (63) to improve identification of the speech sounds.

5. Speech recognition appratus according to any one of the preceding claims, characterised in that the apparatus includes a microphone (5) that derives an output in respect of the sound produced by the speaker, and a comparator (70) that compares the output from the microphone with information derived from the optical device (6) such as to derive information concerning speech sounds made by the user.

6. Speech recognition apparatus according to Claim 5, characterised in that the output of the voicing sensing apparatus (20) and the microphone (5) are combined in order to identify sound originating from the speaker and sound originating from external sources.

7. Speech recognition apparatus according to Claim 6, characterised in that the apparatus includes a store (51, 54) containing a reference vocabulary of sound signal information, a second pattern matching unit (53) connected to the store (51, 54) and connected to receive the output of the microphone (5) after rejecting signals associated with sounds originating from external sources.

8. Speech recognition apparatus according to Claim 3 or 4 and Claim 7, characterised in that the comparator (70) receives the outputs of the first and second pattern matching units (63 and 53) and provides an output representing the most probable speech sounds made in accordance therewith.

9. Speech recognition apparatus according to any one of Claims 5 to 8, characterised in that the apparatus includes a circuit (63, 74) that modifies the output of the microphone (5).

10. Speech recognition apparatus according to Claims 7 and 9, characterised in that the output of the microphone (5) is modified by the output of the first pattern matching unit (63) and that the output of the microphone (5) is supplied to the second pattern matching unit (53) after modification by the first pattern matching unit (63).

Fig.1.

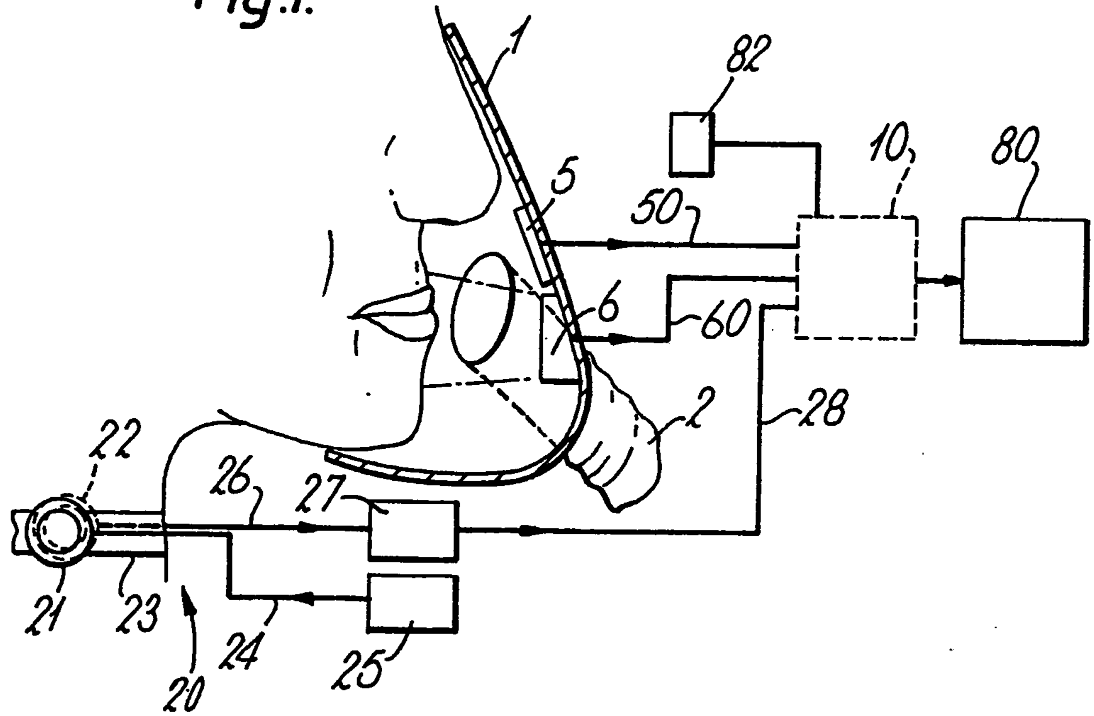
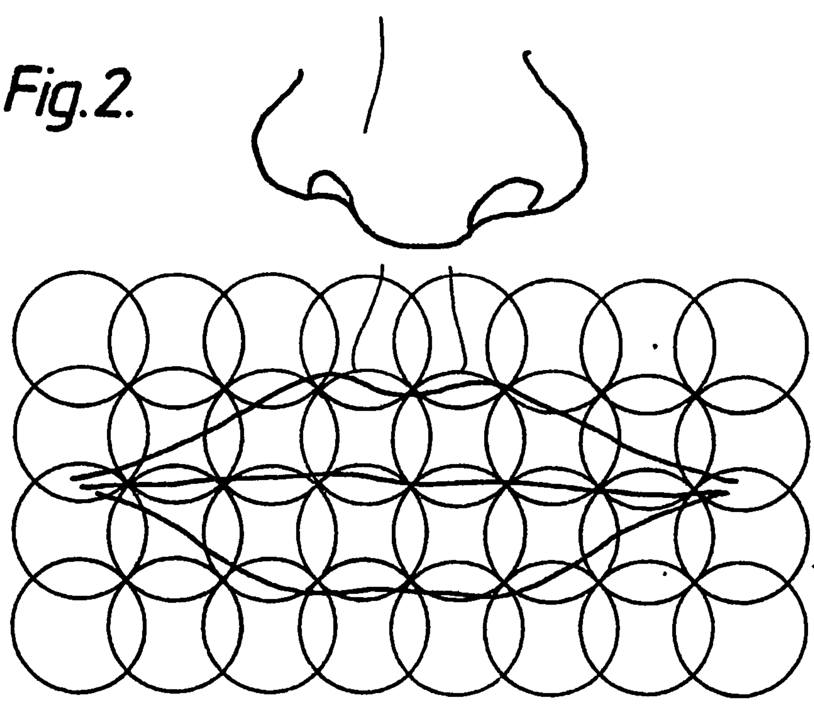
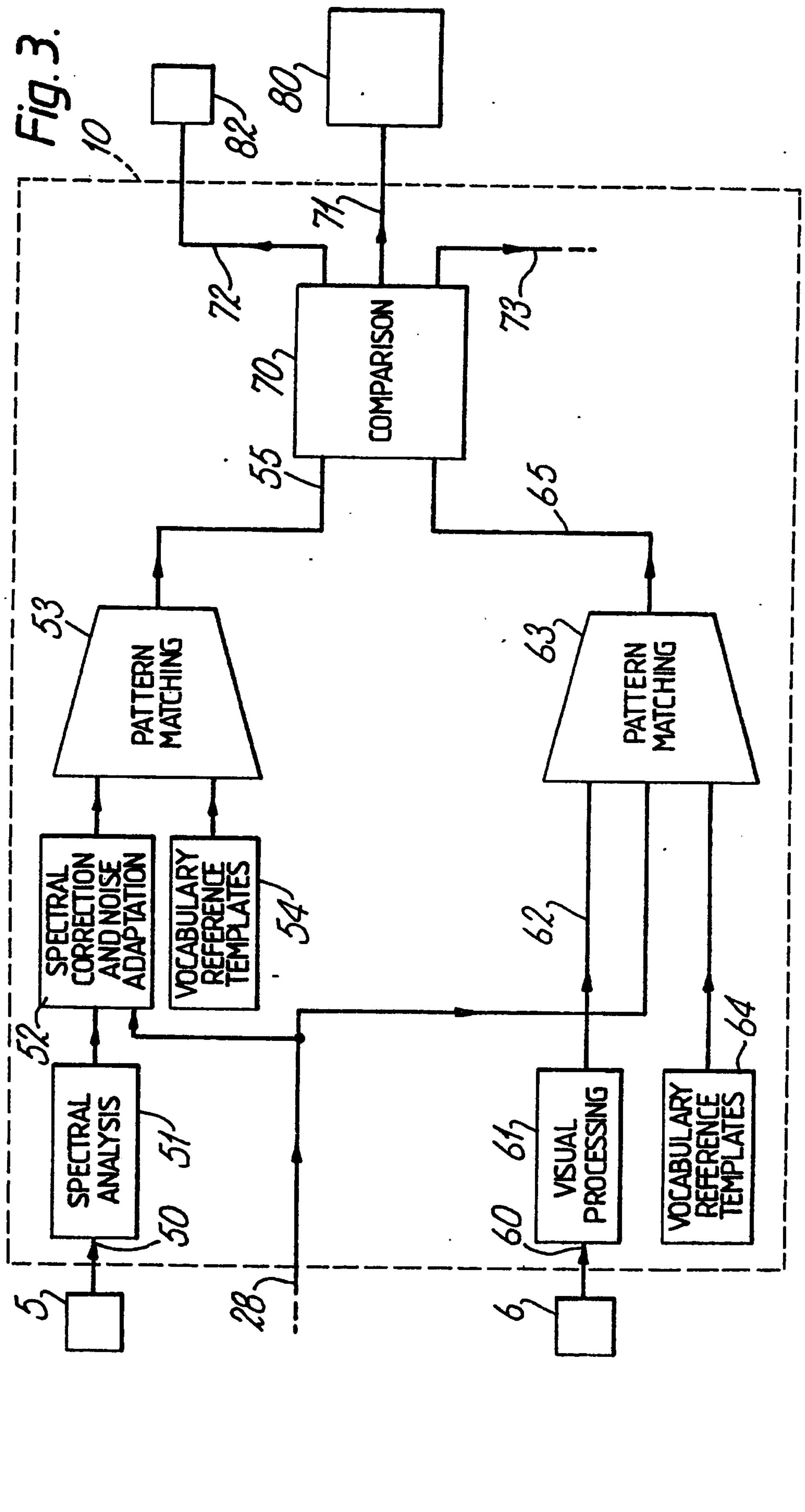


Fig.2.





SPECTRAL ANALYSIS
SPECTRAL CORRECTION AND NOISE ADAPTATION
VOCABULARY REFERENCE TEMPLATES
PATTERN MATCHING
COMPARISON
PATTERN MATCHING
VISUAL PROCESSING
VOCABULARY REFERENCE TEMPLATES
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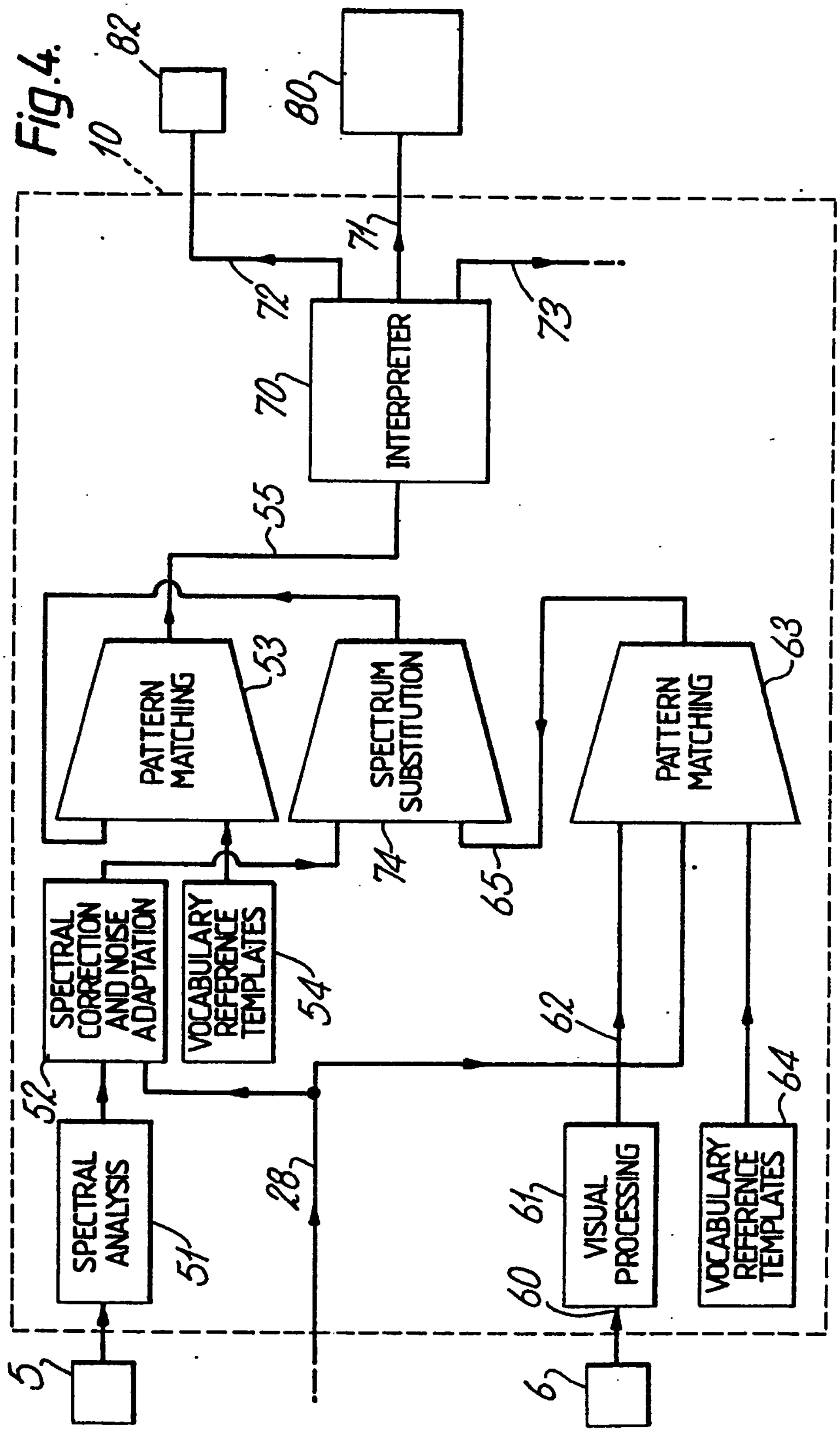
Fig. 3.

Fig.4.



SPECTRAL ANALYSIS
SPECTRAL CORRECTION AND NOISE ADAPTATION
VOCABULARY REFERENCE TEMPLATES
PATTERN MATCHING
SPECTRUM SUBSTITUTION
INTERPRETER
VISUAL PROCESSING
PATTERN MATCHING
VOCABULARY REFERENCE TEMPLATES
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European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 87 30 5087

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	COMPUTER DESIGN, vol. 22, no. 7, June 1983, pages 128-131, Winchester, Massachusetts, US; A. DAVIS et al.: "Advanced data acquisition aids the handicapped" * Pages 128-129; figure 2 *	1	G 10 L 5/06

Y	PROCEEDINGS OF THE IEEE COMPUTER SOCIETY CONFERENCE ON COMPUTER VISION AND PATTERN RECOGNITION, San Francisco, 19th-23rd June 1985, pages 40-47, IEEE; E.D. PETAJAN: "Automatic lipreading to enhance speech recognition" * Abstract *	1	
A	Idem	3	TECHNICAL FIELDS SEARCHED (Int. Cl.4)

A	JOURNAL OF ACOUSTICAL SOCIETY OF AMERICA, vol. 38, no. 5, 1965, pages 790-796; W.A. HILLIX et al.: "Computer recognition of spoken digits based on six nonacoustic measures"		G 10 L 5/00 G 10 L 9/00 G 09 B 21/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	02-11-1987	DELPORTE B.P.M.

CATEGORY OF CITED DOCUMENTS

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